tube ends between the headers and the seal plates, water drum ends of generating tubes, and return bends in economizer tubes. General fireside thinning of a generating tube is shown in figure 12-11.

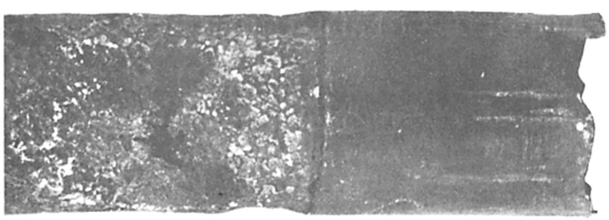
A rather unusual type of general fireside metal loss sometimes results from the combination of extremely high tube temperatures and the burn-ing of fuel oil that contains vanadium compounds. The vanadium compounds carried in the flame can cause rapid oxidation of metal at high temperatures. This type of damage is unusual in water-cooled parts of the boiler, since critical temperatures are not usually attained. Figure 12-12 shows a stainless steel superheater tube that has suffered this type of general thinning as a result of fuel ash damage.

FIRESIDE BURNING occurs when the rate of heat transfer through the tube wall is so reduced that the metal is overheated. Waterside deposits can cause fireside burning, but most serious fireside burning occurs when a tube becomes steam bound or dry. Figure 12-13 shows the coarse, brittle appearance of tube metal that has suffered fireside burning.

STEAM GOUGING occurs when steam jets out of a hole in an adjacent tube. Steam gouging can be identified by the extremely smooth surface of the cavity, together with the irregular shape of the the cavity. As maybe seen in figure 12-14, a steam gouge looks as though the metal has been blasted away and the cavity polished.

TOOL MARKS, such as chisel cuts or hammer scars, can usually be identified without too much trouble. As shown in figure 12-15, tool marks do not resemble corrosion effects in any way.

TUBE DEFORMITIES AND FRACTURES comprise another category of boiler tube damage that covers abnormal bends, blisters, bulges, cracks, warps, sags, and other breaks or distortions. Like the cavities and scars previously discussed, tube deformities and fractures are fairly easy to distinguish by visual observation.

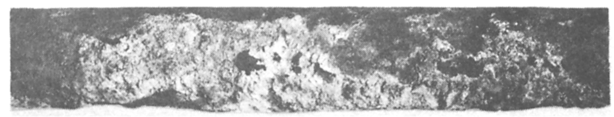


98.139

Figure 12-11.—General fireside thinning of a generating tube.

98.140

Figure 12-12.—General fireside thinning of a stainless steel superheater tube (results of fuel ash damage).



98.141

Figure 12-13.—Fireside burning.

98.142

Figure 12-14.—Fireside steam gauge.

98.143

Figure 12-15.—Fireside tool marks.

The THIN-LIPPED RUPTURE, shown in figure 12-16, is a fairly common tube deformity. The rupture resembles a burst bubble; the open lips are uniformly tapered to sharp, knifelike edges, with no evidence of cracking or irregular tearing of the metal. True thin-lipped ruptures occur in economizer tubes, in generating tubes, and, to a much lesser extent, in superheater tubes. Ruptures of this type indicate that the flow of steam or water was not adequate to absorb the heat to which the tube was exposed; consequently, the tube metal softened and flowed and then burst. Thin-lipped ruptures may be caused by a sudden drop in water level or by tube stoppage from plugs, tools, and so forth, that were accidentally left in the boiler.

Serious THICK-LIPPED RUPTURES resemble the thin-lipped ruptures except that the edges are thick and ragged rather than tapered and knifelike. Thick-lipped ruptures that occur in mild steel generating tubes indicate milder and more prolonged overheating than the overheating that leads to thin-lipped ruptures. Abnormal firing rates, momentary low water, flame impingement, gas laning, and many other causes can produce mild but prolonged overheating that can eventually lead to thick-lipped ruptures. A typical thick-lipped rupture in a generating tube is shown in figure 12-17.

PERFORATION is the term used to de-scribe any opening in a tube (other than a crack) that is NOT associated with tube enlargement. The most common kind of perforation

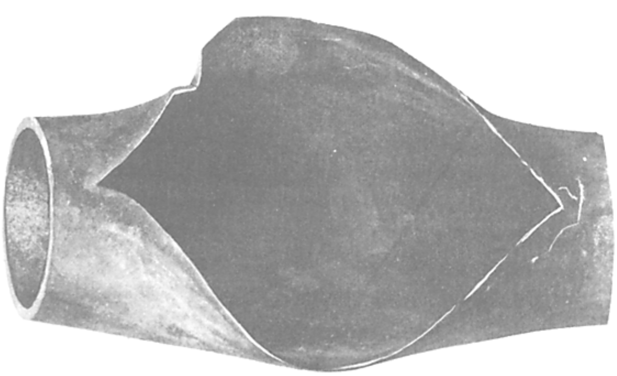


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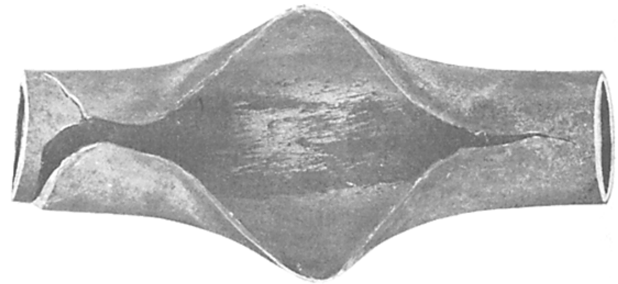
Figure 12-16.—Thin-lipped rupture in a generating tube



98.148

Figure 12-17.—Thick-lipped rupture in a generating tube.

98.150

Figure 12-18.—Thermal crack in a superheater tube.

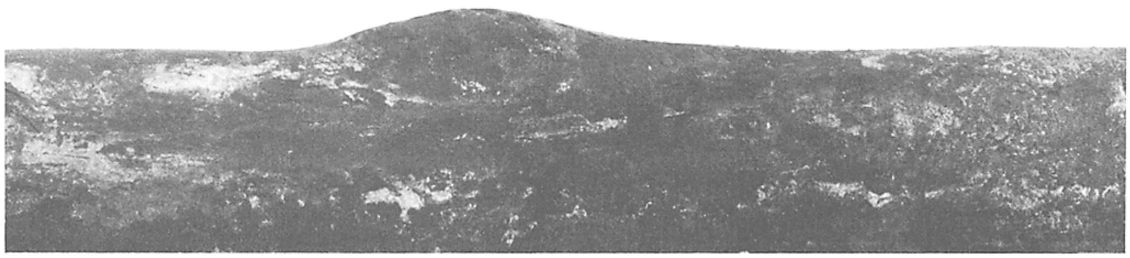
is probably the pinhole leak. In many cases, the first evidence of tube failure is a pinhole leak.

THERMAL CRACKS, sometimes called CREEP CRACKS, result from prolonged, mild overheating or repeated short-time over-heating. Cracks of this type are found most often in alloy superheater tubes, but they can occur in mild steel tubes as well. The tube is not usually enlarged when a thermal crack exists; the cracked wall has normal thickness, and the break has a dark crystalline appearance. A typical example is shown in figure 12-18.

TUBE ENLARGEMENT of the type shown in figure 12-19 is relatively common in super-heater tubes but rare in generating tubes. This uniform enlargement of a portion of the tube is caused by milder overheating than that which produces cracks or ruptures. If an enlarged tube is continued in service, it will almost certainly crack or break.

98.152

Figure 12-19.—Enlarged tube.



98.153

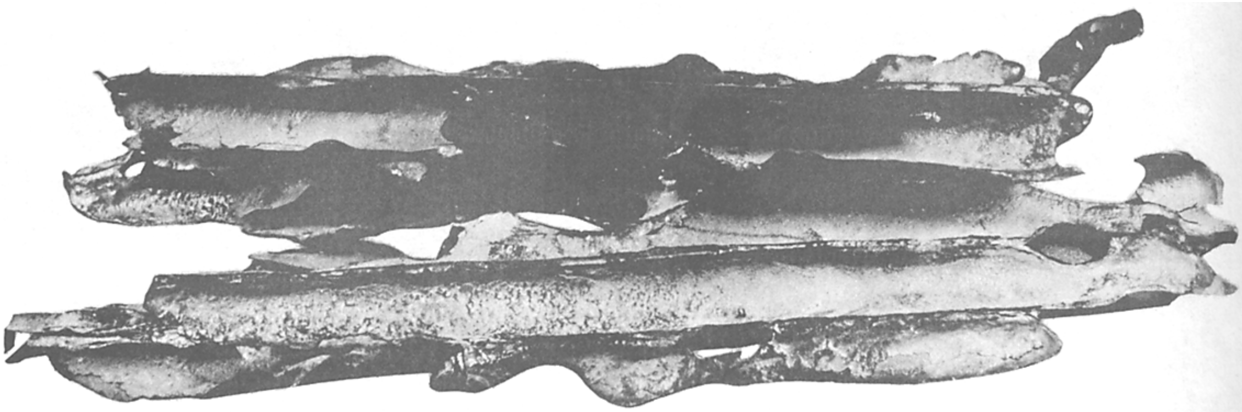
Figure 12-20.—Heat blister on a fire row tube.

HEAT BLISTERS differ from tube enlargements in that they affect only one side of the tube, usually the side toward the fires. Blisters appear as egg-shaped lumps on the fireside. They indicate that the tube has been heated to the softening point and has blown out under boiler pressure. Heat blisters always indicate the presence of waterside deposits. If the deposit is brittle, as scale or baked sludge, blistering breaks the deposit and allows the boiler water to quench the hot metal before the tube bursts. Heat blisters are most commonly found on the fire row generating tubes; they are rarely found on superheater tubes or economizer tubes. A typical heat blister is shown in figure 12-20.

SAGGING is the term applied to tubes that appear to have dropped downward toward the furnace under their own weight. This type of deformation results from semiplastic flow of the tube metal, caused by extremely mild overheating. A momentary condition of low water is probably the most common cause of sagging. If the boiler has been cooled slowly, and if the distortion is not so severe as to interfere with the designed flow of combustion gases, sagged tubes may still be continued in service.

WARPING is similar to sagging except that the distortion is haphazard rather than in one direction. Warping usually occurs as a result of sudden cooling of the tubes after they have been overheated. Cooling a boiler too rapidly after a low-water casualty is a typical cause of warped tubes.

MELTING can occur as a result of a serious low-water casualty. If the tube temperature becomes high enough, the tube metal actually melts and runs down into the furnace. A cluster of fused tubes that resulted from melting is shown in figure 12-21. Melting of aluminum economizer parts can cause tremendous damage to a boiler. The molten aluminum from overheated economizer parts reacts so violently with the iron oxide coating on the steel tubes below that the heat of the chemical reaction may melt the steel tubes even though the furnace temperature is not high enough to melt them.



98.155

Figure 12-21.—Melted cluster of tubes.

98.157

Figure 12-22.—Lamination of a tube wall (fabrication detect).

MECHANICAL FATIGUE CRACKS occasionally occur in boiler tubes from such purely mechanical processes as flexing. Cracks of this type can usually be identified by a clean, bright break through a major portion of the metal thickness. These cracks begin on the outside circumference of the tube.

TUBE WALL LAMINATION is shown in figure 12-22. This lamination or layering occurs during the fabrication of the tube. It is the most common material defect found in boiler tubes.

FOLDED or UPSET TUBES are a result of defective fabrication. A folded tube is shown in figure 12-23. This defect resembles a heat blister in appearance, but the folded tube shows no wall thinning and has a depression on the side of the tube opposite the bulge.

STRETCHED or NECKED TUBES are also a result of defective fabrication. A stretched or necked tube is shown in figure 12-24.

FIRESIDE TUBE DEPOSITS can produce many of the scars and deformities just described. Basically, tube deposits cause tube failure because they lead to localized overheating of the tube

98.158

Figure 12-23.—Tube fold (fabrication defect).

98.159

Figure 12-24.—Stretched or necked tube (fabrication defect).

metal. The accurate identification of tube deposits is often a necessary part of determining the cause of tube failure.

FIRESIDE TUBE DEPOSITS include soot, slag, corrosion products, and high-temperature oxide.

SOOT is a broad term used to cover all of the ash products (other than slag) that result from combustion. These ash products include carbon, sand, salts such as sodium sulfate, and other materials. Soot deposits are usually powdery or ashy on the tube surfaces near the top of the boiler; but they tend to be packed solid on drums, headers, and the lower ends of the tubes.

SLAG is not a powdery or packed ashlike soot; rather, it is a saltlike material that is fused to the tube surfaces. Slag is objectionable on boiler tubes because it retards the transfer of heat to the tube metal and because it may cause gas channeling, with consequent local overheating of tube metal that is not covered by the slag. Most slags on boiler tubes are soluble enough to be controlled by periodic washing of firesides. The main way to prevent slag is to avoid burning fuel oil that is contaminated with seawater.

CORROSION DEPOSITS seldom form major fireside deposits. Occasionally, however, bulky deposits of ferrous sulfate may form as the result of the combination of soot and large amounts of water. These deposits have been known to travel away from their original location and adhere to remote rows of generating tubes. The deposits can usually be removed by water washing and mechanical cleaning. The source of the water leakage should be found and corrected. Also, the location of the original deposit should be found, and the area should be carefully inspected for signs of corrosion.

HIGH-TEMPERATURE OXIDE is the term applied to heavy fireside layers of mixed iron oxides formed by overheating of the tube metal. Low water is a frequent cause of high-temperature oxide on the tube firesides. The high-temperature oxide has a rather layered appearance; it resembles corrosion products and is often wrongly called scale.

Exterior Inspection of Drums and Headers

The exteriors of all boiler drums and headers should be inspected for signs of corrosion under the insulation. Rusty streaks or signs of corrosion on or around the edges of the covering, the drum pads, or the tubes indicate possible corrosion of the drum and should be investigated immediately. If machinery or piping is installed over the boiler, water may drip down on the boiler and work its way under the insulation. In such installations, the boiler drum coverings must be removed, and the exterior of the drum must be inspected carefully.

Inspection of Protection, Seal, and Support Plates

All corrosion-resisting steel plates such as baffle plates, seal plates, superheater support plates, steam drum protection plates, and so forth, must be carefully inspected whenever firesides are opened. These steel plates are subject to damage from overheating, particularly if clogged gas passages interfere with the designed flow of combustion gases and allow extremely hot gases to flow over the plates. Since failure of these parts could have extremely serious consequences, the plates should be inspected at every opportunity and should be renewed when necessary.

Inspection of Uptakes and Smoke Pipes

The uptakes and smoke pipes are examined according to a maintenance system. Check the uptake expansion joints to be sure they are not clogged with soot. Look for ruptures and for loose reinforcing ribs or Z-bar stiffeners. Check the rain gutters to see that they are not plugged with soot. Check the top of the economizer to see if it is clean.

OPERATIONAL INSPECTION AND TESTS

Following the hydrostatic test, the boiler should be fired and brought up to operating pressure and temperature. All automatically and manually operated control devices provided for control of steam and water pressure, hot-water temperature, combustion, and boiler water level should be inspected and caused to function under operating conditions. All associated valves and piping, pressure- and temperature-indicating devices, metering and recording devices, and all boiler auxiliaries should be inspected under operating conditions. All safety valves and water-pressure relief valves should be made to function from overpressure.

Inspections and tests may be made with the main steam or hot-water distribution valves closed or open as necessary to fire the boiler and operate it under normal operating conditions. Testing the function of automatically or manually controlled devices and apparatus that may interfere with distribution requirements should be one with main steam or hot-water distribution valves closed, as applicable.

The purpose of these inspections and tests is to discover any inefficient operation or maintenance of the boiler or its auxiliaries that may be evidenced under operating conditions. All deficiencies requiring adjustment, repair, or replacement, and all conditions indicating excessive operating costs and maintenance costs should be reported.

Firing Equipment

The operation of all firing equipment, including oil burners, gas burners, fuel injectors, fuel igniters, coal stokers and feeders, and other such equipment provided to introduce fuel into the boiler furnace and ignite the fuel, should be inspected for any deficiency that may be evidenced under operating conditions. In particular, igniters and burners should be checked to ensure that burner protrusion, angle, setting, and so forth, is such that light off and operation are as effective as possible.

Controls

Inspect the operation of combustion controls, steam pressure controls, water temperature controls, and feedwater controls. Assure that the ability of the combustion control and steam pressure control to maintain proper steam pressure (or water temperature in high-temperature water installations) and air-fuel ratio is demonstrated throughout the capacity range of the boiler. Air-fuel ratio should be checked by CO_2 or O_2 measuring devices. On smaller boilers the appearance of the fire may be used as a guide for inspection of air-fuel ratio. Check fully automatic boiler controls for proper programming sequence and timing with respect to prepurge, ignition, pilot proving, flame proving, and postpurge periods, Check the operation of flame failure and combustion air failure devices to assure that they properly shutoff the supply of fuel; do this by simulating a flame failure (manually shutting off the fuel or by other means) and observing the operating of the controls, solenoid valves, and diaphragm-operated valves that are to operate during a flame failure. Inspect feedwater controls and check the ability of the controls to maintain proper water level throughout the range of capacity with first load swings. Check the operation of low-water fuel cutoff and automatic water-feeding devices by draining the float bowl, lowering the boiler water level, or by performing other necessary steps to cause these devices to function, to assure they operate properly. The low-flow cutout on high-temperature water boilers should be tested by reducing the flow until cutout occurs. For additional information on the inspection of the operating conditions of the controls, refer to the section of this RTM that deals with WATER COLUMNS AND GAUGE GLASSES.

Steam and Water Piping

While the boiler is operating, examine all steam and water piping—including connections to the columns—for leaks. If any leaks are found, determine if they are the result of excessive strains caused by expansion and contraction or other causes. Listen for water hammer; if found, determine the cause. Look for undue vibration, particularly in piping connections to the boiler. Where excessive vibration of piping is found, examine connections and parts for crystallization.

Water Columns and Gauge Glasses

With steam on the boiler, blow down the water columns and gauge glasses and observe the action of the water in the glass to determine if the connection to the boiler or the blowoff piping is restricted or not properly free. This will help you determine the true condition of high- and low-water alarms and of the automatic combustion equipment.

Devices

While the boiler is operating, cause the individual mechanisms of LOW-WATER FUEL CUTOFF and/or WATER-FEEDING DEVICES to operate to assure they function properly.

Where a float-operated, low-water cutoff or water-feeding device or a combination low-water fuel cutoff and water-feeding device is provided, its operation should be tested by opening the drain to the float bowl and draining the bowl to the low-water level of the boiler. When the low-water point is reached, the mechanism of the low-water fuel cutoff should function and shut off the fuel supply to the boiler until boiler water is added to the proper level. Also, at the low-water point, the mechanism controlling the feedwater supply should function to start the feedwater.

Where there is a low-water fuel cutoff device controlled by excess temperature generated in a temperature element located inside the boiler, its operation may be tested by blowing off the boiler to its allowable low-water level. On or before the low-water level is reached, the device should function to shut off the boiler fuel supply until boiler water is added to the proper level.

On high-temperature water boilers, the flow through the boiler should be restricted to the minimum allowed, as shown by the manufacturer's operating data. The point at which fuel cutoff takes place should be noted and adjustments made as required.

With steam on the boiler, observe the STEAM GAUGE pointer for sticking or restriction of its movement. Blow down the pipe leading to the gauge to assure that it is free. Attach an approved test gauge to the pipe nipple provided for this purpose, and compare the accuracy of each steam gauge on the boiler with that of the test gauge. When inaccuracy of any gauge is evidenced or suspected, it should be removed and calibrated by means of a deadweight gauge tester or other device designed for this purpose. When several boilers are in service and connected to a common steam main, compare the readings of the separate gauges. All TEMPERATURE-INDICATING DEVICES should be observed for indications of excessive temperature, particularly during and immediately after the time high-load demands are made on the boiler. While the boiler is operating under normal conditions, observe the operation of all METERING AND RECORDING DEVICES. When there is evidence that any such device is not functioning properly, it should be adjusted, repaired, or replaced as necessary.

Blowoff Valves

Test the freedom of each blowoff valve and its connections by opening the valve and blowing off the boiler for a few seconds. Determine if the valve is excessively worn or otherwise defective, and if there is evidence of restrictions in the valve or connected piping preventing proper blowoff of the boiler.

Stop and Check Valves

While the boiler is operating, inspect the operating condition of each stop and check valve where possible. Serious defects of externally controlled stop valves may be detected by operating the valve when it is under pressure. Similarly, defects in check valves maybe detected by listening to the operation of the valve or observing any excessive vibration of the valve as it operates under pressure.

Pressure-Reducing Valves

While there is pressure on the system, open and then close the bypass valve as safety and operating conditions permit. Also, observe the fluctuation of the pressure gauge pointer as an aid in determining possible defects in the operation of the pressure-reducing valve or the pressure gauge. Look for any evidence that may indicate improper condition of the relief or safety valves provided for the pressure-reducing valves.

Boiler Safety and Water-Pressure Relief Valves

Test the blowoff setting of each safety valve for steam boilers and each water-pressure relief valve for hot-water boilers by raising the boiler pressure slowly to the blowoff point. In turn, test the releasing pressure of each valve, gagging all other safety or relief valves except the one being tested. Observe the operation of each valve as blowoff pressure is reached. Compare the blowoff setting with setting requirements specified in paragraph 1 or 2 of this section, as applicable, and make adjustments where necessary. When the steam discharge capacity of a safety valve is questionable, it should be tested by one of the methods given in paragraph 3 of this section. When the pressure-relieving capacity of a pressure-relief valve is questionable, it should be tested according to the procedures given in paragraph 4 of this section.

1. SAFETY VALVES—SETTING REQUIREMENTS. Note this word of caution: Before adjusting safety valves on electric steam generators, be sure that the electric power circuit to the generator is open. The generator may be under steam pressure, but the power line should be open while the necessary adjustments are being made. At least one safety valve should be set to release at no more than the maximum allowable working pressure of the steam boiler. Safety valves are factory set and sealed. When a safety valve requires adjustment, the seal should be broken, adjustments made, and the valve resealed by qualified personnel only. When more than one safety valve is provided, the remaining valve or valves may be set within a range of 3% above the maximum allowable working pressure. However, the range of the setting of all the safety valves on the boiler should not exceed 10% of the highest pressure to which any valve is set. Each safety valve should reseat tightly with a blowdown of not more than 2 psig or 4% of the valve setting, whichever is greater.

In those cases where the boiler is supplied with feedwater directly from the pressure main without the use of feeding apparatus (not including return traps), no safety valve should be set at a pressure greater than 94% of the lowest pressure obtained in the supply main feeding the boiler.

2. PRESSURE-RELIEF VALVE—SETTING REQUIREMENTS. At least one pressure-relief valve should be set to release at not more than the maximum allowable working pressure of the hot-water boiler. When more than one relief valve is provided on either hot-water heating or hot-water supply boilers, the additional valve (or valves) may be set within a range not to exceed 20% of the lowest pressure to which any valve is set. Each pressure-relief valve should reseat tightly with a blowdown of not more than 25% of the valve setting.

3. SAFETY VALVE—CAPACITY TEST. When the relieving capacity of any safety valve for steam boilers is questioned, it may be tested by one of the three following methods:

a. By the accumulation test, which consists of shutting off all other steam-discharge outlets from the boiler and forcing the fires to the maximum. The safety valve capacity should be sufficient to prevent a pressure in excess of 6% above the maximum allowable working pressure.

This method should not be used on a boiler with a superheater or reheater.

b. By measuring the maximum amount of fuel that can be burned and computing the corresponding evaporative capacity (steam-generating capacity) upon the basis of the heating value of this fuel. These computations should be made as outlined in the code.

c. By determining the maximum evaporative capacity by measuring the feedwater.

When either of the methods outlined in (b) or (c) above is employed, the sum of the safety valve capacity should be equal to, or greater than, the maximum evaporative capacity (maximum steam-generating capacity) of the boiler.

If you discover that the relieving capacity is inadequate because of deficiencies in the valve, the valve should be repaired or replaced. If the relieving capacity of the valve is found to be satisfactory within the proper relieving range of the valve but inefficient for the steam-generating capacity of the boiler, additional safety valve capacity should be provided.

4. PRESSURE-RELIEF VALVE—CAPACITY TEST. When the relieving capacity of any pressure-relief valve for hot-water boilers is questioned, the capacity can be tested by turning the adjustment screw until the pressure-relief valve is adjusted to the fully open position. The pressure should not rise excessively. When the test is completed, reset the pressure-relief valve to the required setting. This test is made with all water discharge openings closed except the pressure-relief valve being tested. When the discharge is led through a pipe, determine at the time the valve is operating if the drain opening in the discharge pipe is not properly free, or if there is evidence of obstruction elsewhere inside the pipe. If deemed necessary to determine the freedom of discharge from the valve, the discharge connection should be removed. After completing tests and adjustments, the inspector should seal the safety adjustment to prevent tampering.

Boiler Auxiliaries

While the boiler is operating under normal conditions, observe the operation of all boiler auxiliaries for any defects that may prevent proper functioning of the boiler or indicate a lack of proper maintenance of auxiliary equipment. The unnecessary use of multiple auxiliaries or the use of a large auxiliary during a light-load period (when a smaller auxiliary could be substituted) should be discouraged. The maximum use of steam-driven auxiliaries short of atmospheric exhaust should be encouraged. Steam leaks, wastage to atmosphere, and so forth, should be called to the attention of operating personnel. Particular attention should be given to deaerator venting practice. Venting should be held to the minimum required to preclude oxygen entrainment in the feedwater.

When intermittently operating condensate pumps are used, look for any tendency toward creation of a vacuum when a pump starts. If this happens, recommend installation of a small, continuously operating, float-throttled, condensate pump (in parallel with intermittently operating pumps) to assure a condensate flow at all times. If there are a number of intermittently operating condensate pumps, it may be possible to convert one of them (if of small enough capacity) to continuous throttled operation.

PLANT OPERATION

To operate boilers or be a plant supervisor, you need to know all the mechanical details of the boiler you are operating and its associated auxiliaries. However, just knowing this information is not enough. To be a professional boiler operator or plant supervisor, you must develop a keen eye for trouble, a finely tuned ear, and an overall sense of awareness concerning boiler plant operation at all times.

As an operator and/or supervisor of a boiler plant, you must learn to tell the difference between normal and abnormal operating conditions. By training yourself to notice and analyze strange noises, unusual vibrations, abnormal temperatures and pressures, and other indications of trouble, you will be better able to prevent any impending trouble or casualty to the plant.

OPERATORS

Boiler plant operators must maintain accurate records. Logs provide a means of recording continuous data on boiler plant performance and analysis of operation. Logs are arranged for use over a 24-hour period, consisting of three 8-hour shifts. Log entries should be carefully made in columns.

Logs

Information of importance in the operation of boilers must be recorded. This section provides information concerning the type of data that should be recorded in logs.

1. Steam pressures. Steam pressure is recorded by the operator from steam gauges and shows performance of automatic or 'manual control.

2. Steam flow. Actual output of the plant is recorded by the operator in pounds per hour to obtain steam flow. This record determines the number of boilers to operate for greatest efficiency.

3. Feedwater heater. Feedwater-heater pressure indicates whether proper deaerating temperature can be maintained in the heater. Feedwater-heater temperature shows the effectiveness of the feedwater heater. A drop in steam supply pressure or insufficient venting may cause low heater temperature.

4. Feed-pump pressure. Feed-pump pressure indicates effectiveness of the boiler feed pumps. If feedwater supply fails, the pressure reading enables the operator to determine whether or not the difficulty is in the feed pumps. The pumps are defective when the feed-pump pressure reading is below normal.

5. Forced draft. Forced draft is an indication of thickness of the fuel bed. The most satisfactory value varies with different installations and fuels and is determined by actual trial.

6. Furnace draft. Furnace draft, when used in connection with forced draft, should be slightly less than atmospheric pressure to prevent smoke from leaking into the boiler room and overheating the furnace lining. If only an induced or natural draft is used, furnace draft must be sufficient to cause the quantity of air required for combustion to flow into the furnace. Operating with a furnace draft higher than actually required results in excessive air leakage into the setting with an accompanying loss in efficiency.

7. Last-pass draft. Last-pass draft shows actual draft produced by a stack or an induced-draft fan. Fireman should become familiar with last-pass draft at various ratings when the boiler is operating satisfactorily. A decrease in last-pass draft with other conditions constant indicates leaking baffles. An increase in last-pass draft shows that gas passes are becoming clogged.

8. Percent CO_2 flue gas. Percent CO_2 flue gas is a measure of relative quantities of air supplied with fuel. It is kept at a value that has been established as most satisfactory for the plant, fuel, rating, and like factors. In plants not equipped with CO_2 recording meters, this value is determined with a hand gas analyzer. With experience, you can determine the correct amount of air supplied for a furnace by checking the draft gauges and from personal observation. In all cases, you should check values by use of a hand gas analyzer.

9. Flue-gas temperature. Flue-gas temperature is an indication "of the portion of heat "leaving the boiler with the flue gases. This heat represents a direct energy loss in fuel. Abnormally high flue-gas temperatures at a given boiler rating are caused by dirty heating surfaces or leakage of baffles. If the heating surface has a coating of soot and ash, heat that cannot escape is discharged to the stack. Leakage through baffles allows the gases to take a shorter path than intended and reduces contact of gases with the entire heating surface. Excessive fouling of the boiler's firesides increases the draft loss while leaking baffles decreases the draft loss. Either condition raises the temperature of flue gases above normal.

10. Fuel. Always determine the quality of fuel being used as this represents a major operating cost.

a. Pounds of coal. Procedures for determining the quantity of coal burned depends upon the means available. You may use scales that automatically dump weighed quantities of coal into the stoker or pulverizer hoppers. A register indicates the number of "dumps" that, multiplied by the weight of coal discharged per dump, gives the total. Another weighing method uses traveling larries equipped with scales so that the weight of each load can be recorded before it is dumped into the boiler hopper. In the absence of a weighing device, the quantity of coal consumed can be determined by filling and leveling bunkers at given intervals and recording the coal used from the report of coal received during a given interval. Methods for approximating coal burned by counting stoker revolutions are only estimates and are subject to considerable error when the size of coal changes.

b. Cubic feet of gas. The quantity of gas used is indicated on a meter. The readings can be direct or they may necessitate calculation by use of a meter factor.

c. Gallons of oil. Fuel oil quantities are determined by use of a measuring stick. Tables supplied with a given tank are then used to determine quantity from level of fuel. Tanks may also be supplied with gauges that can be read directly.

11. Outside temperature. A heating plant load is greatly influenced by outside temperature. Record this temperature for comparison with steam generated and fuel used. These comparative values are useful in determining abnormal fuel consumption and in estimating future requirements.

12. Makeup water. The quantity of makeup water used should be recorded. This enables the operator to note an abnormal increase in makeup water before a dangerous condition develops. Return all possible condensate to the boiler plant; this will save on water and chemicals being used to treat the water.

13. Water Pressure. Feedwater is most important to the safe operation of the boiler plant. The hot-water supply temperature should be recorded. Insufficiently heated water can cause scaling or deposits in a boiler.

14. Hot-water supply temperature. Record the hot-water supply temperature. Insufficiently heated water can cause scaling or deposits in a boiler.

15. Water softeners. Where softeners are employed, you should keep a meter record to inform the shift operator of the time when the units must be regenerated. A decrease in the time of runs between regeneration is an indicator of either an increase in hardness of incoming water or of deterioration of the softening material. The note columns are for recording total water softened and pounds of salt added.

16. Totals and averages. Space is provided for recording total and average quantities per shift.

17. Steam flow. To find the quantity of steam generated, subtract the steam flowmeter integrator reading at the start of shift from the reading at the end of the shift, then multiply the remainder by the meter constant. Dividing steam generated by fuel burned (pounds of coal, cubic feet of gas, or gallons of oil) yields a quantity that indicates the overall economy obtained. If the plant does not have a steam flowmeter, pumps can be calibrated for flow and a record kept of their operating time, or the condensate and makeup water can be metered.

18. Boiler feed pump in service. A record of the boiler feed pump in service makes it possible to determine appropriate operating hours and to see that the various pumps are used for equal lengths of service.

19. Soot blown time and blowdown. A record of blown time and blowdown is valuable to the relieving shift operator because it is an indicator of plant conditions, and it will show irregularities if any exist.

20. Phosphate, caustic soda, and tannin added. A record of phosphate, caustic soda, and tannin used is valuable in keeping correct boiler water analysis and in determining the total amount of chemicals used.

21. Remarks. The remarks column is in the upper right area of the log sheet. List all the equipment that is to be checked each day according to the schedule listed in TM 5-651. Annotate all the irregularities that are found in connection with these inspections. List the dates when the boilers are drained and washed and at other intervals, as determined by local water conditions. Indicate the degree of internal cleanliness.

22. Using personnel. Names of personnel responsible for these data must be entered in the appropriate area on the bottom of the log sheet.

Turnover/Watch Relief

When an operator comes on duty, he should make an operational inspection to ensure that everything is operating normally. The points to be checked are as follows:

1. Check the water level in the gauge glass on each boiler by opening and closing the try cocks.
2. Check the low-water cutoffs and the boiler feed equipment by blowing down the water columns on each boiler.
3. Check the steam pressure and compare it with the steam pressure that the plant should deliver.
4. Check the boilers for leaks or other conditions that can affect plant operation.
5. Check for proper operation of the boiler room accessories.
6. Check the fuel supply and the firing equipment.
7. Check the condition of the fires to determine if they are clean.
8. Check the general appearance of the boiler room, fixtures, piping, and insulation.
9. Check the boiler room record sheets to determine if any troubles were encountered by the previous shift operator.
10. Question the operator being relieved about plant operation and the troubles encountered.
11. Check for any verbal or written orders with which you are to comply.

Table 12-2.—Effects of Inadequate or Improper Water Conditioning

EFFECT	CONSTITUENT	REMARKS
Scale	Silica	Forms a hard, glassy coating on internal surfaces of boiler. Vaporizes in high-pressure boilers and deposits on turbine blades.
	Hardness	$CaSO_4$, $MgSO_3$, $CaCO_3$ and $MgCO_3$ form scale on boiler tubes.
Corrosion.	Oxygen	Causes pitting of metal in boilers, and steam and condensate piping.
	Carbon dioxide	Major causes of deterioration of condensate return lines.
	O_2 - CO_2	Combination is more corrosive than either by itself.
Carryover.	High boiler water concentrations.	Causes foaming and priming of boiler and carryover in steam, resulting in deposits on turbine blades and valve seats.
Caustic embrittlement.	High caustic concentration.	Causes intercrystalline cracking of boiler metal.
Economic losses.	Repair of boilers.	Repair pitted boilers and clean heavily scaled boilers.
	Outages	Reduce efficiency and capacity of plant.
	Reduced heat transfer.	High fuel bills.

PLANT SUPERVISOR

As a boiler plant supervisor, you are expected to organize and manage the overall operation of the boiler. Ensuring that daily logs are maintained by operators, submitting monthly operation reports and logs, checking maintenance requirements, training personnel, and so forth, are included in your duties and responsibilities. Each boiler plant has its unique requirements. Only through operating your specific plant and completely familiarizing yourself with it can you establish a comprehensive management program.

This chapter cannot cover all the aspects of supervising a boiler plant. You must refer to current Navy publications and manufacturer's manuals that pertain to your specific plant. When assigned as a boiler plant supervisor, -establish an on-site library of these publications and manuals, and keep them handy for immediate reference.

WATER CHEMISTRY

The effects of inadequate or improper water conditioning can cause major problems in the operation of boilers. Manufacturer's specifications must be strictly adhered to. Table 12-2 outlines the effects and results of poor water treatment of boiler water. By establishing an aggressive water-treatment program, you can greatly reduce inefficient boiler operation and high maintenance costs.

CHEMICAL MAKEUP OF WATER

Water is called the *universal solvent.* The purer the water, that is, the lower its dissolved solids content, the greater the tendency to dissolve its surroundings. Pure water, if stored in a stainless steel tank after a short contact time, has a very small amount of iron, chromium, and nickel from the tank dissolved in it. This dissolving of the tank does not continue indefinitely with the same water. The water, in a sense, has satisfied its appetite in a short time and does not dissolve any more metal. Pure water, if exposed to air, immediately absorbs air and has oxygen from the air dissolved in it. A glass of tap water at 68°F contains 9.0 ppm of oxygen. Tap water heated to 77°F contains 8.2 ppm of oxygen, and some oxygen is driven out of the water. The higher the temperature of the water, the less dissolved oxygen it can hold. Conversely, the higher the pressure imposed on the water, the greater the dissolved oxygen it can hold. Water, when boiled, produces steam. The steam contains some liquid water. There is never a perfect separation of pure steam from the boiling water. The steam above the boiling water always has entrained with it some boiling water. The foregoing three ideas: water is a universal solvent, water dissolves oxygen when in contact with air, and boiling water is always entrained with steam should help you understand the nature of feedwater.

The feedwater, as it enters the boiler steam drum, is now considered boiler water. Complete understanding of the nature of boiler water can be gained by temporarily making the assumption that no water treatment, chemical addition, or blowdown is applied to the boiler water. The character of the boiler water continually changes as the boiler steams. The dissolved and suspended solids, contained in the feedwater, concentrate in the boiler water at the rate of eightfold every hour if the boiler is producing steam at 50 percent of its normal capacity. Three damaging conditions arise in the boiler as the boiler water continues to steam wit bout treatment. *Scale formation* on the steam generating surfaces, *corrosion* of the boiler metal, and boiler water *carry-over* with the steam due to foaming are the three results of untreated boiler water.

To prevent scale formation on the internal water-contacted surfaces of a boiler and to prevent destruction of the boiler metal by corrosion, you must chemically treat feedwater and boiler water. This chemical treatment prolongs the useful life of the boiler and results in appreciable savings in fuel since maximum heat transfer is possible when no scale deposits occur.

CHEMICAL TREATMENT (EXTERNAL AND INTERNAL)

The method of using chemicals may take the form of external treatment, internal treatment, or a combination of both. The principal difference between these forms of treatment is that in external treatment the raw water is changed or adjusted by chemical treatment outside of the boiler so a different type of feedwater is formed. In internal treatment, the water is treated inside the boiler by feeding chemicals into the boiler water, usually through the feed lines. Again, in external treatment the main chemical action takes place outside the boiler, while in internal treatment the chemical action takes place within the boiler.

INTERNAL TREATMENT AND PREVENTION

At many Navy installations, the boilers are not large and do not operate at high pressure. When the makeup water is not too high in hardness or dissolved solids, good operation is possible with only internal treatment. Under this condition, external treating equipment is unnecessary. Chemical treatment covered in this chapter applies primarily to internal treatment.

Scale

When water evaporates in a boiler, the hard components that were in the water, such as calcium salts, magnesium salts, and other insoluble materials, form deposits on the tubes and other internal surfaces. These deposits are known as scale. Actually, the temperature of the water determines how well the different salts dissolve and how long they remain dissolved. Some salts are such that the hotter the water, the better they stay dissolved. Other salts stay dissolved while the water is at a relatively low temperature but form

Table 12-3.—Chemicals Used by NAVFAC for Internal Boiler Water Treatment in Shore-Based Boilers

CHEMICAL	PURPOSE	COMMENT
Sodium hydroxide $NaOH$ (caustic soda).	increase alkalinity, raise pH, precipitate calcium sulfate as the carbonate.	Contains no carbonate, therefore doesn't promote CO_2 formation in steam.
Sodium carbonate Na_2CO_3 (Soda ash)	Increase alkalinity, raise pH, precipitate magnesium.	Lower cost, more easily handled than caustic soda. But some carbonate breaks down to release CO_2 with steam.
Soduim phosphates NaH_2PO_4, $NaHPO_4$, Na_3PO_4, $NaPO_3$.	Precipitate calcium as hydroxyapatite ($Ca_{10}(OH)_2(PO_4)_6$).	Alkalinity and resulting pH must be kept high enough for this reaction to take place (pH usually above 10.8).
Sodium aluminate $NaA1_2O_4$.	Precipitate calcium, magnesuim	Forms a flocculent sludge.
Soduim sulfite Na_2SO_3	Prevent oxygen corrosion.	Used to neutralize residual oxygen by forming sodium sulfate. At high temperatures and pressures, excess may form H_2S in steam.
Hydrazine hydrate $N_2H_4.H_2O$ (35%).	Prevent oxygen corrosion.	Remove residual oxygen to form nitrogen and water. One part of oxygen reacts with three parts of hydrazine (35% solution).
Filming amines; Octadecylamine, etc.	Control return-line corrosion by forming a protective film on the metal surfaces.	Protects against both oxygen and carbon dioxide attack. Small amounts of continuous feed will maintain the film. Do not use where steam contacts foods.
Neutral amines; morpholine, cyclo-hexylamine, ben-zylamine.	Control return-line corrosion by neutralizing CO_2 and adjusting pH of condensate.	About 2 ppm of amine is needed for each ppm of carbon dioxide in steam. Keep pH in range of 7.0 to 7.4 or higher.
Sodium nitrate $NaNO_3$	Inhibit caustic embrittle-merit	Used where the water may have embrittling characteristics.
Tannins, starches, glucose and lignin derivatives.	Prevent feed line deposits coat scale crystals to produce fluid sludge that won't adhere as readily to boiler heating surfaces.	These organics, often called protective colloids, are used with soda ash, phosphate. Also distort scale crystal growth, help inhibit caustic embrittlement.

Table 12-3.—Chemicals Used by NAVFAC for Internal Boiler Water Treatment in Shore-Based Boilers—Continued

CHEMICAL	PURPOSE	COMMENT
Seaweed derivatives; (Sodium alginate, Sodium mannuronate).	Provide a more fluid sludge and minimize carryover.	Organics often classed as reactive colloids since they react with calcium and magnesium and absorb scale crystals.
Antifoams; (polyamides, etc.).	Reduce foaming tendency of highly concentrated boiler water.	Usually added with other chemicals for scale control and sludge dispersion.
Proprietary compounds (of ball or brick type).	Do not use for water treatment	Boilers 125 psig and above, all power plant boilers, all boilers using intermittent blowdown.
	May be used for water treatment	Low makeup boilers (under 125 psig) for space heating.
		High makeup boilers (under 125 psig) with continuous blowdown and stable feedwater, if cost saving is effected.

solid crystals (scales) that come out in increasing amounts as the water gets closer to becoming steam.

The scale-forming salts stay dissolved in the water and in the cooler parts of the boiler, but when the water reaches the hot tubes, these salts start forming solid particles that come out of the water and stick to the hot metal parts as scale deposits. These deposits are highly objectionable because they are poor conductors of heat, actually reduce efficiency, and are frequently responsible for tube failures. Some of the principal scale-forming salts to be considered in most cases are listed as follows:

Calcium sulfate	$CaSO_4$
Calcium silicate	$CaSiO_3$
Magnesium silicate	$MgSiO_3$
Calcium hydroxide	$Ca(OH)_2$
Calcium carbonate	$CaCO_3$
Magnesium hydroxide	$Mg(OH)_2$

Scale is made up of three main parts: calcium sulfate, calcium carbonate, and silicates of calcium and magnesium. Scales that are principally calcium sulfate or chiefly of the aforementioned silicates are very hard; those scales that are principally calcium carbonate with little silicate are somewhat softer. A scale consisting chiefly of calcium carbonate may appear only as a thin, porous, soft scale that does not build up in thickness.

Scale can be prevented by the intelligent use of proper water treatment, and that is one of the objectives of the boiler water test and treatment program.

Prevention and Treatment for Scale Control

Scale-forming substances cannot always be prevented from entering the boiler, but they can be made to form a fluid sludge. The problem then is simply one of proper chemical treatment and blowdown.

The selection of chemicals for internal treatment is determined by many factors: the kind of feedwater hardness (whether carbonate or sulfate); the ability of feedwater to build up required causticity; the type of external treatment, if used; the pH and percentage of condensate returns; the location of chemical feed injection; and the cost and availability of chemicals.

The first two chemicals to be considered for boiler water treatment of shore-based boilers are caustic soda and sodium phosphate (table 12-3).

The caustic soda prepares the way by making the water definitely alkaline (high pH). The sodium phosphate can then attack the calcium magnesium and silica salts and convert them into a fluid sludge that can be removed by blowdown.

Caustic soda is used when the feedwater cannot build up the required causticity residual in the boiler water. Use of soda ash (Na_2CO_3) is not authorized in steaming boilers because it breaks down under heat to form undesired carbon dioxide (CO_2). This gas is corrosive to condensate return lines. The Navy boiler compound customarily used aboard ship is not authorized because it contains about 39% soda ash.

Sodium phosphate ($NaPO_4$) has a special affinity (attraction) for calcium, and in boiler water the phosphate joins with calcium to precipitate calcium phosphate ($CaPO_4$).

Phosphate prevents the formation of calcium scales, such as calcium sulfate, calcium carbonate, or calcium silicate. The precipitate of calcium phosphate develops as a finely divided fluid material that can readily be removed by blowdown. The sodium phosphate dosage should be regulated to maintain a residual reading of 30 ppm to 60 ppm.

Sludge

Another source of tube coating is BAKED SLUDGE. This sludge comes from dirt, oil, water-treatment chemicals, and so forth, that are suspended in dirty feedwater. The solids settle on tube surfaces and absorb the heat intended to be transferred to the water. The heat then cooks the sludge into a hard coating on the tube walls. These deposits are as hard or harder to remove than TRUE SCALE and should be recognized as a completely different problem. Methods of preventing and combating baked sludge are different from methods of preventing and combating scale.

Baked sludge is very hard to remove by mechanical means, and boiler compound has no effect on it at all. The best method found to combat sludge is to know where it comes from, make it gather by proper treatment, and blow it out before it cooks.

Prevention and Treatment for Sludge Control

When the proper causticity residual is maintained and phosphate is fed in correct amounts, the scale-forming impurities in boiler water sludges out and should be easy to blow out. Sometimes, however, the characteristics of the precipitated chemicals are such that the sludge formed does not go along with the water and leave the boiler with the blowdown. It has been discovered that additives called sludge conditioners cause the sludge to flow better. Most sludge conditioners are organic substances that act as dispersants. They keep the sludge in a fluid state by holding the precipitates as finely divided particles. As the precipitated chemicals settle, a loose fluid mass that is easy to blow out is formed. The only sludge dispersant approved by NAVFAC for use in shore-based boilers is QUEBRACHO TANNIN.

Generally, when quebracho tannin is used, sufficient quantities are fed to the boiler to give the boiler water a medium tea color. [f the causticity residual is high, a darker color should be maintained. This darker color for high causticity aids in preventing hardening of metal in the boiler. As the tannin particles become part of the sludge and are blown out, the brown color, given to the water by the initial dose of tannin, becomes a lighter color, and more tannin must be added.

Proper blowdown is important because some sludges are almost always in the boiler water. When only parts of the boiler are badly sludged, blowdown may not be complete or there are areas of poor circulation. The boiler design may be such that even good blowdowm does not clear all the parts. Another concern is that frequency, time, and the kind of blowdown being used may not be complete or correct to maintain optimum conditions.

A small amount of seawater in the feedwater causes heavy sludging. Where seawater is likely to contaminate feedwater or where evaporated seawater is used for feedwater, every precaution should be taken to prevent saltwater contamination of the feedwater. Regular daily boiler water tests will show up contaminated feedwater so that it car be corrected before serious harm is done.

Where makeup water is clean and not much sludge shows at bottom blowdown, tannin may not be necessary. Where there is a lot of sludge, the addition of tannin is a big help in keeping the boiler free and clean. Also, much less sludge-forming materials are required when the raw water makeup is upgraded by external treatment.

Corrosion

Corrosion is the deterioration of metal by Chemical action. When dissolved oxygen is present in the boiler water, corrosion begins and continues until all metal has been transformed into iron oxide or, commonly stated, rust. When rust forms in the boiler, it may drop out as sludge or cling to other metal surfaces. It is not economically possible to prevent at least some of the iron in the boiler from going into solution. All iron not protected by a coating or film of something that keeps out moisture and air is sooner or later going to become RUST. The idea is to slow down the process as much as possible by KEEPING OXYGEN OUT and by maintaining a proper causticity residual.

The pH level of boiler water is also a factor in corrosion. The active agent in the corrosion of the internal water surface of boilers is oxygen; however, the combined action of oxygen and the acid action of the water are required for the corrosion process. To suppress the acid action of the water, you can raise the pH value of the water by adding caustic soda. The lower the pH value, the stronger the acid concentration. The higher the pH value, the weaker the concentration. Economically, acid corrosion cannot be stopped completely, but it can be suppressed by keeping oxygen out of the boiler and by maintaining a proper pH value and causticity range.

Prevention and Treatment for Oxygen Corrosion

The chemical most commonly used in oxygen removal is sodium sulfite, and it is quite often referred to as an oxygen scavenger. It is an example of a chemical that actually reacts with the harmful constituent. It reacts with oxygen, forming a neutral compound—sodium sulfate.

When enough sodium sulfite is fed into a boiler so that a surplus of the chemical is maintained, any of the oxygen getting into the boiler water is taken up by the chemical, and the boiler water is kept virtually free of oxygen. By maintaining a suitable residual, little, if any, corrosion due to oxygen occurs. Common practice in feeding sodium sulfite is to maintain a surplus residual of about 20 ppm to 50 ppm in the boiler water. This is generally enough sodium sulfite to react with normal amounts of oxygen that might get into the boiler. Higher concentrations of sodium sulfite are unnecessary.

Sodium sulfite dissolves readily in water and must be fed at a point between the feed heater and the boiler so that it is used to take up only the oxygen that gets by the deaerator or heater. If the sodium sulfite is fed through the feed lines by continuous feeding, it is always present in the feed lines and takes up oxygen in the feedwater in addition to maintaining a surplus in the boilers.

Another advantage of using sodium sulfite is that if, for any reason, a feedwater heater or deaerator becomes inoperative or efficient operation is temporarily interrupted, the sodium sulfite residual present in the boiler water can take up the larger amounts of the oxygen getting in. At the same time, the concentration of sodium sulfite drops. This is shown by test analysis of the boiler feedwater. This test gives the operator ample warning of an existing malfunction within the boiler feedwater supply system. Immediate steps should be taken to correct this off-standard condition. Feedwater or makeup water tanks should be heated to a temperature of 180°F to 200°F. This heat alone helps to dispense of most of the dissolved oxygen before it can enter the boiler. It also allows for more economical use of sodium sulfite.

The prevention of corrosion in the boiler means regulating the alkalinity of the water, producing protective films, and removing dissolved oxygen. These preventive measures are accomplished by maintaining the proper chemical residuals in the boiler water and by proper deaeration.

Carryover—Foaming and Priming

The word *priming* is used rather loosely to express the action of the water and steam in a boiler when an unusual amount of water is being carried over with the steam. For a given boiler installation, a certain amount of water or moisture in the steam is tolerated. The amount depends upon the use of the steam, the boiler construction, and the facilities for removing the water from the steam. The mechanical causes include deficiency in boiler design, high water level, improper method of firing, overloading, and sudden load changes. A poorly designed boiler may have insufficient steam disengaging space. It is fairly obvious that the faster the steam is produced in a given vessel, such as a boiler, the more violent is the boiling effect. But when the steam space above the water level is large enough, the steam leaving the boiler does not show any evidence of carryover. The size of the steam header and the velocity of steam leaving the boiler are, therefore, important elements in boiler design. As the rate of steam production goes up, so does the tendency for steam contamination. The sudden opening of a steam valve or the cutting in of a boiler too quickly speeds up the production of steam, which can cause violent bubbling and carryover.

The primary chemical causes of carryover are high concentrations of totally dissolved and suspended solids in the boiler water, excessive alkalinity, and the presence of oil.

Foaming is the production of froth or unbroken bubbles on the surface of the boiler water. The froth may be thin, with few bubbles overlying each other, or it may build up throughout the steam space. Under such conditions it is difficult to free the steam of the liquid films, and the moisture content increases. When certain substances are dissolved in water, they concentrate somewhat more in the body of the liquid than on the surface; others concentrate more on the surface than in the body. In either case, the surface tension of the water is affected, and bubble film develops. The formation of froth depends upon the tenacity of the films of liquid that form the shells of the bubbles. A tough film can develop that refuses to break and release the steam. Apparently, finely divided solids in suspension increase the stability of the film so that the combination of salts in solution and finely divided solids cause foaming to develop more readily than when either one is present by itself. Soaps getting into the boiler from outside sources or formed within the boiler from oils or animal greases intensify the foaming action. Water can be carried over in the steam without formation of froth. When a pure water that does not foam is boiled, it frequently "bumps" as unstable steam bubbles are formed. These rapidly reach the surface of the water and instantaneously burst through. Parts of the water tend to become superheated and suddenly turn to steam. Fine solid particles released in water under these conditions cause the immediate production of much steam. This may occur in a boiler when particles of scale suddenly become loose.

When a boiler is foaming or priming, it is difficult and quite often impossible to read the true level of the boiler water on the gauge glass. The slugs of boiler water can wreck turbines or engines. The carryover of boiler water solids, usually caused by foaming and priming, disrupts operation of the equipment coming in contact with the steam, Deposits form in steam piping, valves, superheaters, engines, or turbines. These solids erode the turbine blades and frequently create out-of-balance conditions to the rotor. They often clog tubing, a pipe, and other apparatus following the boiler. When live steam is used for processing purposes or for cooking, the solids can seriously damage the final product. Remember also, any moisture carryover with the steam is an additional heat loss through the steam line.

Prevention and Treatment for Carryover—Foaming and Priming

There are two kinds of solids present in most boiler water—the dissolved solids, or substances that are in solution, and suspended solids. Suspended solids are finely divided solid particles floating around in the water. This is material left over after the scale-forming and corrosive salts have been changed into sludge by chemical treatment.

When a boiler is steaming, the feedwater continuously carries dissolved mineral matter into the boiler. However, the steam leaving the boiler carries very little mineral matter with it. The concentration of dissolved solids in the boiler water, therefore, keeps building up unless properly controlled by continuous or intermittent blowdown.

In water tube boilers, concentrations are generally highest at the place where (he mixture of steam and water from the tubes spills over into the steam drum. Where total concentrations are not reduced sufficiently by the bottom blow, another blowdown line should be installed to remove water from the drum at the point where TDS (total dissolved solids) concentrations are the highest. This blowdown is generally operated continuously when the boiler is in service and is called a continuous blowdown.

The best remedy for foaming and priming carryover is the proper blowdown of TDS. The continuous blowdown should be regulated to maintain the TDS at 3,000 to 4,000 ppm. The greater the TDS that can be carried without trouble, the less water, fuel, and chemicals required or wasted in the TDS blowdown.

CHEMICAL TREATMENT DETERMINATION

Because raw water conditions vary so greatly with locale, it is impossible to recommend a single, specific water treatment. Whenever possible, a water treatment chemist should be consulted and his or her recommendations for the chemical treatment of boiler water should be followed. The degree of success of any water treatment program depends upon how well the recommendations for treatment are monitored. When the services of a qualified water treatment chemist are obtained, his or her recommendations should include the following:

- The treatment formula
- The treatment ingredients
- Instructions to the boiler operator in the use of the treatment
- Periodic visits to the plant to check on the results of the treatment plan

When the operator follows instructions and uses the proper blowdown procedure, scale and sludge in the boiler are reduced to a minimum. Blowdown limits the amount of dissolved and suspended solids in the boiler water.

Consulting a chemist is an ideal situation. Seabees seldom operate under ideal situations, particularly during contingency operations. How do you determine the initial chemical treatment for a boiler, and then, how do you establish an effective treatment program? Some general guidelines follow.

The first determination you have to make is the steaming rate of the boiler, expressed in pounds per hour. This is a fairly simple computation. You first determine the boiler horsepower (bhp); then multiply the result by 4.5 pounds. For example, if you have a 100 horsepower boiler operating at one-half fire, your steaming rate is 1,725 pounds of steam per hour.

1 BHP = 34.5 lb steam/hour
100 x 34.5 = 3,450 steam/hour at high fire
3,450 ÷ 1/2 =1 .725 lb steam/hour at one-half fire

To determine the initial chemical dosage, you must know the hardness of the raw water. A chemist can tell you this; however, in the field you must determine it by experimentation. The harder the water, the more phosphates you must add during treatment to obtain correct phosphate residuals. The example that follows assumes zero hardness of the raw water and uses a 1,725-pound steaming rate. 1. Mix the following chemicals in 28 gallons of water:

a. 1 1/4 pounds of sodium sulfate
b. 1/2 pound of trisodium phosphate
c. 1/2 pound of caustic soda

2. Adjust the chemical feed rate to 3 gallons per hour (allows for 8- to 10-hours of steaming).

The chemical dosage varies with the steaming rate of the boiler. To establish your water treatment program, use the following steps every hour of operation for the duration of your initial chemical batch.

1. Determine the hourly steaming rate
2. Test for phosphate residual (30-60 ppm)
3. Test for sulfite residual (25-50 ppm)
4. Test for pH (9.5 to 11.5)
5. Test for TDS (3,000 to 4,000 ppm)

You should make a log entry of these test results every hour. This establishes a history of the test results. At the completion of the initial chemical dosage, you can either add or subtract chemicals, based on your log. It may take several batches fed over an 8 to 10 hour period to get a consistent chemical requirement for boiler water treatment. Once the boiler has stabilized and treatment test results remain reasonably balanced, testing may be required only every 4 hours.

At this time you can chart your chemical requirements, based on load demand of the boiler. By establishing this history through experimentation, your operators are able to treat the boiler water with fairly accurate results. At this time note that boiler blowdown has a big effect on your treatment program. Proper blowdown practices cannot be overemphasized. Too little blowdown causes TDS readings to be high; too much blowdown causes a high demand for chemicals and results in lost efficiency of the boiler.

MAINTENANCE

The subject of boiler maintenance covers a wide range of topics.

Major repairs that involve welding of pressure parts of the boiler are done by Steelworkers in strict adherence to the procedures in section IX of the ASME (American Society of Mechanical Engineers), "Boiler and Pressure Vessel Code." This section is concerned with operator and preventive maintenance and major considerations for the maintenance and care of firesides and watersides. Procedures for laying up idle boilers are also discussed.

OPERATOR MAINTENANCE

Operator maintenance is the necessary, routine, recurring maintenance work performed by the operators to keep the equipment in such condition that it may be used continuously, at its original or designed capacity and efficiency for its intended purpose. The operator is actually the most important member of the maintenance team. A well-informed and responsible operator can do the following:

1. Keep equipment in service for maximum periods of time.

2. Detect any flaws so equipment can be removed from service in time to prevent serious damages.

3. Perform minor repairs on equipment removed from service to minimize outage time.

It is sometimes difficult to determine where operator duties end and maintenance crew work begins. However, the operator must realize that he or she has the keenest interest in the condition of the equipment. A well-kept plant not only reflects the operator's interest (and the desire to better his or her position) but it also is vital to the safety of equipment and personnel. It is essential for every person in the operating aisle to perform the following duties:

1. Clean. Dirt is the principal cause of equipment failure. Whether it is fly ash in the switch gear, oil on the deck, cloth lint, or dust, it causes trouble. No matter the form in which dirt appears, it should be removed immediately by the operator.

2. Lubricate. Any two surfaces brought together develop friction. If not properly lubricated, these surfaces wear one another down, change clearances, and cause equipment breakdowns. A well-placed drop of oil or a thin layer of grease can go a long way toward keeping a much-used piece of equipment in good condition.

3. Cool. Every piece of equipment has an operating temperature range. The operator should be informed on this matter. An unusual change in temperature that the operator cannot correct should be reported immediately to the plant supervisor. When the temperature of a piece of equipment rises rapidly, an immediate shutdown is recommended,

4. Tighten. Vibration is another major source of equipment failure. A simple step taken in time, such as tightening of bolts, can prevent a serious failure. Equipment that is not secured properly, vibrates, causes an unbalance, vibrates further, and compounds a cycle that can only lead to further trouble. In making rounds, the operator should put his hand on the bearings, touch the fan housing, and feel the motor casing. When any unusual sound is heard, vibration felt, or motion seen, the proper steps should be taken by the operator to correct the condition.

PREVENTIVE MAINTENANCE

Preventive maintenance inspection (PMI) is a system of routine inspections of equipment recorded for future reference on some type of inspection record. The purpose of PMI is to anticipate and prevent possible equipment failures by making periodic inspections and minor repairs in advance of major operating difficulties. Preventive maintenance directed specifically toward maintaining boiler efficiency is the exception, rather than the rule. Rising fuel costs have placed an increasing emphasis on conscientious maintenance because it results in higher boiler operating efficiency. Preventive maintenance practices are easily justified from an economical and safety standpoint. Tables 12-4 and 12-5 reflect NAVFACENGCOM recommendations for PMI.

Table 12-4.—PMI Checklist for Steam Boilers 350,000 Btuh or Less

STEP	IF	THEN	WHEN
Observe condition of flame	Flame is smokey, flame impinges on furnace walls or burner starts with a puff	Make appropriate repairs or adjustments	Weekly
Test low water and fuel cutoff	Boiler does not secure during tests	Locate problem and repair	Weekly
Test water column or gauge glass	Gauge glass is dirty, has an obstruction, or leaks are present including gauge cocks	Clean, remove obstructions or repair leaks, or replace	Weekly
Observe operation of condensate of vacuum pumps	Pump is defective or leaking	Repair or replace pump	Weekly
Check operation of chemical feed pots and pumps	Leaks or improper operation exists	Repair or replace defective equipment	Weekly
Test flame detection devices and associated automatic fuel cutoff valves	Loss of flame does not shut off fuel to burner	Repair or replace valves or defective equipment	Monthly
Inspect steam supply and condensate return piping	Problems with valves, radiators, trap leaks, or excessive rust	Repair or replace defective equipment	Monthly
Inspect fuel supply systems and piping. Include adjustment of oil pressure and ensure both oil supply and return lines have a fusible in-line valve	Discrepancies are leaks, or insulation is missing	Repair or replace for corrective action	Monthly
Check condition of safety valves	Valves are obstructed to flow, inoperative, or fail to meet code requirements	Repair or correct the problem	Monthly
Check boiler room drains	Drains are not operating properly	Repair	Monthly
Inspect burner assembly	Evidence of improper fuel nozzle wear, plugging, or carbon buildup exists	Replace nozzle and adjust equipment after new nozzle is installed	Monthly

Table 12-4(Continued).—Checklist for Steam Boilers 350,000 Btuh or Less

STEP	IF	THEN	WHEN
Inspect burner assembly, replace fuel filters and nozzle on oil burning equipment, clean and adjust electrodes			Annually
Internal and external inspection of heating surfaces after cleaning			Annually
Inspect gas piping valves for proper support and tightness	Leaks are present	Secure piping to the boiler and contact the gas company	Annually
Check transformer	Transformer is replaced for any reason	Do not interchange transformers of different capacities	Annually
Remove trash			Annually
Check draft, manifold pressure, and combustion. Overfire draft should be .02" water gauged for oil burners	Deficiencies are noted	Repair, adjust, or replace defective mechanism	Annually
Inspect control equipment for proper sequence and operation	Covers are missing, controls are dirty, or electrical contacts are fouled	Replace, clean, or repair	Annually
Calibrate and check operation of gauges and meters	Gauges are defective, cracked, have broken glass, or bent pointers	Have gauges calibrated, repaired, or replaced	Annually
Check shell for cleanliness, excessive rust, corrosion streaks, deformations, and cracks			Annually
Check stack and breaching for integrity and tightness			Annually

Table 12-5.—PMI Checklist for Hot-Water Boilers

STEP	WHEN
Observe condition of flame	Weekly
Check fuel supply and note oil level	Weekly
Observe operation of circulating pumps. Lubricate pump motor bearing assembly and flex coupling	Weekly
Test flame detection devices and associated automatic fuel cutoff valves	Monthly
Inspect fuel supply systems and piping in boilers for leaks and loss of insulation	Monthly
Check boiler room drains for proper functioning	Monthly
Check condition of safety relief valves	Monthly
Inspect burner assembly	Monthly
Internal and external inspection of heating surfaces after cleaning	Annually
Inspect gas piping and valves regularly for proper support and tightness	Annually
Check transformer	Annually
Inspect area around boiler for cleanliness	Annually
Inspect hot-water supply and return piping and valves	Annually
Check draft, manifold pressure, and combustion. Conduct combustion efficiency tests and adjust burner for safe and efficient operation	Annually
Check expansion tank and air eliminator equipment	Annually
Check control equipment for proper sequence and operation	Annually
Calibrate and check operation of gauges and meters	Annually

Table 12-5(Continued).—PMI Checklist for Hot-Water Boilers

Check breaching and stack for integrity and tightness	Annually
Check shell for cleanliness, excessive rust, corrosion streaks, deformations, and cracks	Annually

EFFICIENCY MAINTENANCE

Efficiency-related boiler maintenance is directed at correcting any condition that increases the amount of fuel required to generate a given quantity of steam. Thus, at a specified boiler load, any condition that leads to an increase in flu-gas temperature; flue-gas flow; combustible content of flue gas or ash; convection or radiation losses from the boiler exterior, ductwork, or pipe; or blowdown rates is considered an efficiency-related maintenance item. Generally, attention to items can eliminate more serious consequences, such as damage to equipment and/or injury to personnel.

The boiler tune-up is the best method of improving efficiency. The primary objective of a tune-up is to achieve efficient combustion with a controlled amount of excess air, thus reducing the dry gas loss and the power consumption of forced- and induced-draft fans.

CARE OF BOILER FIRESIDES

The boiler firesides must be kept clean. The burning of any petroleum product tends to be incomplete, thus leaving soot and carbon deposits on the boiler firesides. These deposits seriously reduce the efficiency of the boiler. Slag contributes greatly to failure of such parts as superheater support plates, baffles, protection plates, and soot blowers. Deposits also act as insulation and prevent the transfer of heat to the water or steam in the tubes.

Soot and slag accumulations that block the gas passages through the tube banks require the use of high air pressures to force the combustion gases through the boiler, thus reducing fireroom efficiency. Accumulations that block the gas passages also interfere with the designed flow of combustion gases and cause extremely hot gases to pass over protection plates, baffles, seal plates, and other parts that are not designed for such high-temperature gases; in some cases, early failure of these parts can be blamed directly on blocked gas passages and the resulting overheating of the parts.

When soot is allowed to remain on the boiler firesides for any length of time, the sulfur in the soot combines with moisture and forms sulfuric acid. This acid attacks tubes, drums, and headers. The extent of the damage caused by acid attack depends upon the length of time the soot remains on the tubes and upon the amount of moisture present during this interval. Moisture may be present as a result of high atmospheric humidity; rain or snow coming down the stack; leaky boiler tubes; and steam or water leakage through the boiler casing joints, particularly from machinery and piping installed above the boiler.

One indication of soot corrosion is the development of pinhole leaks at the point where the tubes enter the water drums and headers and at other points where it is difficult to clean the tubes properly. When soot corrosion is allowed to proceed unchecked, extensive deterioration of the boiler metals results.

You will find that keeping the firesides clean actually saves work, as well as saving the boiler. Clean tubes do not collect deposits as readily as dirty tubes do. It is a good deal easier to clean the firesides several times when they are only slightly dirty than to clean them once when they are heavily coated with soot and carbon.

Local instructions usually specify steaming intervals after which the boiler firesides must be cleaned. In addition to this upkeep, the firesides are normally cleaned just before to the annual internal inspection.

Although there are a number of cleaning methods available (such as hot-water washing, wet-steam lancing, and so forth), mechanical cleaning should be considered the basic and preferred method of cleaning firesides. The other methods are generally used only when mechanical cleaning cannot adequately remove the fireside deposit.

Mechanical cleaning is accomplished within the boiler, in the furnace, and from outside the boiler through access doors by using various types of scrapers, probes, and wire brushes to remove soot and other deposits. In most instances, these cleaning tools can be obtained from the boiler manufacturer.

In addition to scrubbing and cleaning the firesides of the generating tubes, other areas of the firesides should receive scrupulous cleaning as well. Particular care should be given to those more or less inaccessible portions of the firesides that are not cleansed by the soot blowers. Any encrusted soot should be removed from burner impeller plates, bladed cones, and drip pans. The furnace refractory must also be cleaned. This operation is perhaps best done last to remove not only original deposits from the brickwork but also soot and dust deposited after other parts of the boiler were cleaned. It is important to keep the brickwork clean for two reasons: First, soot and foreign matter lodged in expansion joints can obviously prevent proper expansion of refractories when hot, and can ultimately cause serious cracking of the brickwork; second, soot and other deposits left on the brickwork will lower the melting point of the refractories.

CARE OF BOILER WATERSIDES

Failure to keep boiler watersides clean reduces the efficiency of the boiler and contributes to overheating, thus leading to serious damage. Experience has shown that tube failures resulting from defective materials or poor fabrication are rare. The majority of all tube failures, other than those associated with water-level casualties, are caused by waterside deposits or accumulations. Some tube failures are caused by waterside deposits of hard scale. More frequently, however, tube failures occur as the result of an accumulation of relatively soft materials such as metal oxides, the residue of chemicals used for boiler water treatment, the solids formed as a result of the reactions between scale-forming salts or other impurities and the chemicals used for boiler water treatment.

As in the case of fireside cleaning, waterside cleaning is usually accomplished after specified steaming intervals and also before the annual internal inspection.

The need for cleaning watersides or firesides is often signaled by a gradual rise in the stack gas temperature. In other words, deposits on either the firesides or watersides of generating tubes reduce heat transfer from the furnace to the water. A good part of the nontransferred heat is, as you know, retained by the fireside or waterside deposit. However, some of the heat not properly carried away by the water and not absorbed by the deposits remains with the combustion gases. Therefore, [he temperature of the stack gas rises.

When working in the watersides of a boiler, you should take all possible precautions to keep tools, nuts, bolts, cigarette lighters, and other small objects from sliding down into the tubes. Some required precautions are as follows:

1. Remove all small objects from your pockets before entering the boiler.

2. Keep an inventory of all the tools and equipment you take into the boiler. Ensure that you remove each item and check it off the inventory before closing up the boiler.

3. Do NOT set tools or other articles down in places where you are likely to forget them. For example, you must not leave tools on top of the steam separators or in other places that are easy to reach but hard to see.

4. When an article is lost in the boiler watersides, you must NOT close up or operate the boiler until the article has been located and removed. Even a very small article can interfere with boiler circulation and cause tube ruptures.

Additional precautions for waterside work include the following:

1. Close, wire, and tag all steam, water, and air valves that could possibly admit fluid to the boiler. Disconnect (or otherwise render inoperative) the remote operating valves as well.

2. Be sure that adequate ventilation is provided before entering the waterside of a boiler.

3. Be sure that all portable extension lights are of the watertight globe type, with the globe encased in a rubberized, metal cage. Be sure all lights are grounded and wires are not broken. Examine the wires from end to end to be sure that the insulation is not broken or cracked, exposing the bare wire.

4. Station a person outside the drum whose ONLY duty is to act as tender and to assist personnel working in the drum.

Boiling out is a special waterside cleaning technique. There are two approved methods for boiling out boilers—the sodium metasilicate pentahydrate method and the trisodium phosphate method. The method used depends upon the purpose of the boiling out. The sodium metasilicate pentahydrate method is used to remove rust-preventive compounds and other preservatives; consequently, this method is used for boiling out (1) newly erected boilers, (2) reactivated boilers, and (3) boilers that have had major tube renewals. The trisodium phosphate method is used when you are boiling out for the removal of oil and for scale softening in preparation for mechanical cleaning.

LAYING UP IDLE BOILERS

Many operators faithfully and carefully follow all the procedures and regulations concerning boiler water treatment only to find that the watersides, nevertheless, experience corrosion and pitting. It should come as no great surprise that the fault is not with the treatment methods, but rather the manner in which the boiler is permitted to stand idle. After the pressure drops within an idle boiler, air gradually seeps into the boiler, carrying oxygen with it. The air also contains carbon dioxide that combines with the boiler water to form carbonic acid, which, in turn, lowers the residual causticity of the boiler water. Gradual in-leakage of feedwater can dilute and lower the causticity of the boiler water even further. In addition, condensation within the boiler, on both waterside and firesides, can produce water droplets that are saturated with oxygen and contain no causticity. Conditions within the boiler are now ideal for active and rapid corrosion. The need for protecting boilers that are left idle for any length of time should be obvious.

Laying Up a Boiler by the Wet Method

A wet lay-up is done after a thorough cleaning of both firesides and watersides. The feedwater used to fill the boiler is deaerated as much as possible. While the boiler is being filled, add caustic soda in sufficient quantities to maintain a pH reading of 9.5 to 11. Additionally, add approximately 0.03-0.06 pounds of sodium sulfite per 1,000 gallons of boiler holding capacity to maintain 30-60 ppm. When equipment is installed in a plant and used in acid treatment of feedwater, it should never be used to fill a boiler for idle standby; this results in a low pH in the boiler, as concentration by boiling is taking place. To ensure the boiler is filled completely, you should add water until it overflows at the top of the boiler through any convenient outlet, and then close the outlet. When there is a superheater on the boiler, add water to fill it completely. If appreciable air is dissolved in the water, you should boil the water to vent out any air after the boiler is nearly filled.

When the chemical feeding system installed is not suitable for continuous feeding and it is necessary to slug feed the chemical while the boiler is being filled, the boiler water must be mixed to obtain uniform distribution of the chemical throughout the boiler. This can be achieved by using a circulating pump to pump water from one section of the boiler to another. When such a pump is not available, mixing can be accomplished by heating the boiler just enough under low fire to set up natural circulation.

After a boiler has been filled for standby, it must be kept filled as long as it is idle with no water flowing in or out. Leakage out, as through a leaky blowdown valve, can admit air and form a waterline in the boiler. A method sometimes used for keeping a boiler completely full consists of using a small tank placed above the boiler with a line connected to any outlet of the boiler or the superheater header. This method also shows when any leakage occurs into or out of the boiler. The small tank is provided with a vent and a water column. When the boiler is filled, water is added up into the tank. Then, if water leaks out of the boiler, water from the tank flows in, keeping the boiler full. When the level in the tank rises, it shows that water is leaking into the boiler, either through the feed line or the steam line.

Water in an idle boiler should be sampled and analyzed weekly. When the causticity or the concentration of sulfite drops considerably, you should ensure additional chemical is fed and the boiler water circulated to distribute the chemical uniformly.

One disadvantage of using the wet method is that when the temperature of the water in the boiler is lower than the outside temperature, condensation or moisture occurs on the outside of a metal boiler, causing corrosion. Some engineers coat the outside of a metal boiler with light oil to help protect it from corrosion.

Laying Up a Boiler by the Dry Method

Dry lay-up should be used when a boiler is scheduled to be out of service for a long period of time or when a boiler is in danger of freezing. The first step is to clean both firesides and watersides of the boiler thoroughly. After cleaning the boiler, the watersides must be completely dried, because any moisture remaining on the surface will cause corrosion. Take precautions to preclude entry of moisture in any form from steam lines, feed lines, or surrounding air.

Place a moisture-absorbing material, such as quicklime, in the boiler at a rate of 2 pounds, or silica gel at the rate of 5 pounds, for 30 cubic feet of boiler volume. Place the chemical-absorbing material in trays and insert it in the drums or manholes. Air carries moisture; ensure that you close all of the manholes and handholes. This method requires checking the moisture-absorbing material every 3 months.

One method of dry lay-up for a large utility type of boiler is to simply feed nitrogen through the boiler vents while draining the boiler. With this method, maintain nitrogen pressure at 5 psig during the storage period.